Plasma Processing Apparatus

BACKGROUND OF THE INVENTION

The present invention relates to plasma processing apparatuses and, particularly, it relates to a plasma processing apparatus capable of conducting stable processing.

In recent years, miniaturization and high-integration for semiconductor devices such as ULSI (Ultra Large Scale Integration) have been progressed rapidly, and devices with fabrication size of 0.13 μm will soon be put into mass production and devices of 0.1 μm size have now been also under development. In addition, improvement in the operation speed of LSI has been progressed rapidly and Cu wiring and low dielectric constant films have now been used for decreasing wiring delay. Further, the structures of devices have also been complicated and kinds of films to be used have become more versatile.

Further, to increase the number of chips obtainable per one wafer sheet, it is necessary to constitute a production line capable of handling wafers of large diameters such as 300 mm. This has demanded higher accuracy and applicability to larger diameters in etching techniques. In particular, in etching oxide films, it is necessary to form contact holes for wiring, fabricate organic or inorganic low dielectric constant films for forming damascenes and, further, fabricate various

masks, which increases the number of steps.

As the device size is reduced to about 0.1 μm, dimensional fabrication accuracy at the nanolevel in view of a CD (Critical Dimension) value is demanded. Further, in etching, when it is intended to obtain a high etch selectivity to the underlying film or the resist film, "etch stop" in which an etching reaction is stopped in the course of processing or "RIE (Reactive Ion Etching-Lag)" in which an etching rate differs depending on the bore diameter to be fabricated (to be etched) is liable to occur. That is, it is difficult to provide compatibility between the aspect vertical fabrication and high selectivity. Further, as the kind of films to be fabricated differs, the processing gas also varies, and distribution of plasmas or radicals in the processing chamber also varies in accordance therewith. Therefore, control means for plasmas or radicals is also important.

In addition to the problems described above in view of the performance, it has also been demanded for the suppression of formation of obstacles caused by deposition of fluorocarbon gases or radicals used upon processing for example to the inner wall of the processing chamber, or countermeasure for reducing the exchange cost of consumed parts such as silicon plates constituting the inner wall of the processing chamber.

JP-A No. 8-339984 discloses a parallel plate type plasma processing apparatus, which applies two different RF

(Radio Frequency) voltages to opposing electrodes when processing insulative films by utilizing plasma. In this apparatus, an upper electrode and a lower electrode are vertically disposed oppositely to each other in the processing chamber, radio frequency power is supplied to at least one of the upper and lower electrodes to ionize and dissociate processing gases introduced into the processing chamber and wafers are processed by using resultant ions or radicals.

JP-A No. 8-288096 discloses a plasma processing apparatus comprising an upper electrode made of a silicon plate formed with a gas hole for introducing gas into a processing chamber and a permanent magnet disposed in a ring-like configuration on the back of the upper electrode.

JP-A No. 2000-36484 discloses a plasma processing apparatus for fabrication of organic low dielectric constant films, in which radio frequency waves at 13.56 MHz are supplied to a lower electrode, coils are disposed on the periphery of the processing chamber and radio frequency waves at 13.56 MHz are supplied to the coils, and in which electrostatic shields are disposed between the coils and a dielectric wall for preventing consumption of the dielectric walls.

Further, Manual for RIE apparatus Exelan 2300 manufactured by Lam Research Corp. discloses a plasma processing apparatus in which high frequency waves at two

kinds of frequencies (2 MHz, 27.12 MHz) are applied to an electrode mounting a workpiece to be processed thereon to generate plasma from the wafer mounting side, so that the voltage is not applied to a silicon plate disposed on the surface opposing to the wafer, thereby preventing consumption of the silicon plate.

In the apparatus of JP-A No. 8-339984, along with increase in the high frequency to be used, high frequency waves penetrate between the upper electrode and a cooling metal plate or in a discharge port (gas blowing port). Since the depth of penetration is extremely thin (1 mm or less), a high electric field is applied to the penetration portion tending to cause abnormal discharge. Once abnormal discharge occurs, the diameter of the blowing port is enlarged to generate plasma even further inside, causing formation of obstacles. In addition, since the potential on the upper electrode is naturally increased by the high frequency waves, the electrode is scraped by sputtering plasma. This may sometimes increase the frequency of exchanging Si upper electrodes, which are expensive consumption parts.

In the apparatus of JP-A 8-288096, magnetic fields are locally formed at a restricted portion having the size substantially equal to that of the permanent magnet. When it is intended to increase the confinement effect by the magnetic fields, the magnetic fields near the permanent magnets are

increased in strength partially to thereby increase the plasma density at this portion. Further, since bias is applied to the RF electrode to draw ions in the plasma, sputtering occurs locally. This results in local consumption of the electrode to sometimes increase the amount of obstacles formed and lower the reliability of the apparatus.

In the apparatus of JP-A 2000-36484, the coils are wound around the lateral side of the processing chamber and plasma is generated by induction coupling. In this case, scraping of the local wall in the processing chamber caused by the increase in the voltage applied to the coils is prevented by electrostatic shields (Faraday shields). Accordingly, the shielding effect is not uniform between the openings and portions other than the openings of the electrostatic shields. Further, plasma ignitionability is sometimes degraded.

In the apparatus of Manual for RIE apparatus Exelan 2300 manufactured by Lam Research Corp., since two kinds of higher and lower high frequency waves are supplied from the wafer to generate high density plasma on the side of the wafer, the increase of the etching rate can be expected. On the other hand, since the plasma or radicals prevail also to the surface opposing to the wafer mounting surface, they attack also the opposing walls (or silicon substrate surface). Accordingly, scraping or film deposition occurs on the opposed surface.

Further, since ions are incident on the wall due to the potential difference between the plasmas and the wall, the plasma potential fluctuates in accordance with the potential on the side of the lower frequency supplied from the wafer mounting electrode. Further, since ions are incident on the wall due to the potential difference between the plasmas and the wall, it is difficult to control the energy of the ions incident on the wall independently of the wafer potential. Accordingly, it is sometimes difficult to control the scraping of the wall or deposition.

As described above, in the parallel plate type plasma processing apparatus, the voltage on the electrode itself applied with the high frequency sometimes becomes high. Further, in the apparatus of generating plasma from the wafer mounting electrode, a ground electrode is etched due to the difference between the potential of the counter electrode serving as the ground and the plasma potential.

A silicon plate is used for the counter electrode formed on the surface opposing to the wafer with a view point of generation of obstacles or with a view point of scavenging F (fluorine) radicals (F radicals in the gas phase are adsorbed to Si in the form of SiFx to decrease). In this case, the silicon substrate is consumed at an early stage. Since the silicon substrate is expensive, reduction in the amount of consumption of the silicon plate is necessary also with a view

point of reducing the manufacturing cost.

SUMMARY OF THE INVENTION

In view of the foregoing problems, the present invention has been made and it is an object of the present invention to provide a plasma processing apparatus capable of continuing stable processing with a period of maintenance extended.

In accordance with the present invention, the following means are adopted in order to solve the foregoing problems.

In accordance with an aspect of the present invention, there is provided a plasma processing apparatus comprising a vacuum reactor having processing gas introduction means and evacuation means, a shield electrode formed on the side of the outer circumferential wall of the vacuum reactor, and a specimen placing device having an antenna electrode for radiating high frequency electric power into the vacuum reactor, wherein first high frequency power is supplied to the antenna electrode, and high frequency electric power at a frequency lower than that of the first high frequency electric power is supplied to the antenna electrode and the shield electrode.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the invention will

become apparent from the following description of embodiments with reference to the accompanying drawings in which:

Fig. 1 is a view for explaining a plasma processing apparatus according to a preferred embodiment of the present invention;

Fig. 2 is a view for explaining another embodiment of the invention;

Fig. 3 is a view for explaining a further embodiment of the invention;

Fig. 4 is a view for explaining a still further embodiment of the invention; and

Fig. 5 is a view for explaining a still further embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is to be described by way of preferred embodiments with reference to the accompanying drawings. Fig. 1 is a view for explaining a plasma processing apparatus according to a preferred embodiment of the present invention. A vacuum reactor 1 constituting the plasma processing apparatus has a wall of a dielectric body 14 such as made of quartz at the inside thereof to form a processing chamber 2. Further, an antenna electrode 51 and a specimen bench 5 for placing a specimen (wafer) 4 as an object to be processed are provided inside the processing chamber 2. A

processing gas is introduced from an upper part of the processing chamber 2 and the introduced processing gas 3 is exhausted by an exhaustion system 6. A suscepter 7 is disposed on the outer circumference of the wafer processing surface of the specimen bench 5. A first high frequency (UHF or VHF) power source 8 used for generating plasma and a second high frequency power source at a frequency lower than that of the first high frequency power source 8 for use in drawing ions are supplied to the antenna electrode 51.

The first high frequency power source 8 and the second high frequency power source 9 are supplied respectively by way of a coaxial wave guide channel 10 to the specimen bench 5 and the antenna electrode 51. A dielectric body 12 is filled between the specimen bench 5 and a metal wall 11 to electrically insulate them from each other. Further, the specimen bench 5 has a cooling device 13 and the temperature of the specimen bench 5 can be controlled by allowing coolant to flow in the cooling device 13. A second electrode (shield electrode) 15 is disposed on the outside of the dielectric body 14 constituting the processing chamber 2. In addition, a third high frequency power source 16 is connected to the shield electrode 15. The third high frequency power source 16 may be at a frequency equal to that of the second high frequency power source.

Wafer processing by using the plasma processing

apparatus is to be described by way of example of etching an oxide film. First, the specimen 4 is conveyed by a conveying device not shown onto the antenna electrode 51 in the processing chamber 2. A processing gas 3 comprising, for example, fluorocarbon gas, O_2 and Ar is introduced into the processing chamber 2 and, after setting the pressure in the processing chamber 2 to a predetermined value, electric power of the first high frequency power source 8 is supplied by way of the coaxial wave guide channel 10 to the antenna electrode 51. The first high frequency power source 8 is passed through the dielectric body 12 and radiated by way of the suscepter 7 into the processing chamber 2 to generate plasma in the processing chamber 2.

The processing gas is dissociated by the generation of the plasma to form fluorocarbon radicals CFx, CxFy or O, and the fluorocarbon radicals are deposited on the wafer. In a case where the second high frequency power source 9 is applied to the antenna electrode 51, a sheath is formed on the specimen 4, by which ions are incident on the fluorocarbon films deposited on the specimen 4, allowing etching to proceed. Reactive products formed by the etching are deposited on the dielectric body 14 as the wall of the processing chamber 2 like fluorocarbon radicals.

A second electrode 15 is disposed on the outside of the dielectric body 14. By controlling the voltage applied to the

electrode, the potential on the surface of the dielectric body 14 can be set to a value slightly lower than the plasma potential. When the surface potential of the dielectric body 14 is set as described above, ions at low energy can be incident on the dielectric body 14. The incidence of the ions at low energy can suppress the reactive products or radicals from depositing onto the surface of the dielectric body 14. That is to say, when the surface in the vacuum reactor is covered with the dielectric body 14 and further a voltage is applied to the second electrode 15 to apply the electric field on the surface of the inner wall of the dielectric body 14, deposition of the reaction products or the radicals on the inner wall can be prevented and the surface of the wall of the dielectric body 14 is always refreshed, so that formation of obstacles can be suppressed effectively.

Fig. 2 is a view explaining another embodiment of the invention. As shown in the drawing, coils 17 are disposed on the outer circumference of the wall of a dielectric body 14 constituting a vacuum reactor of a plasma processing apparatus. A third high frequency power source 16 is supplied to the coils 17. The frequency of the third high frequency power source 16 may be identical with that of the second high frequency power. A metal Faraday shield 18 is disposed between the coils 17 and the dielectric body 14 and on the upper surface of the wall of the dielectric body 14. A

variable capacitor 19 or a variable inductor is connected to the Faraday shield 18. The lateral surface 18a of the Faraday shield 18 may be of a blind-like structure in which metal stripes and slits are arranged alternately. In addition, the ceiling part 18b of the Faraday shield 18 may be of a shape having an opening 181 or a shape not having the opening 181. In the drawing, portions identical with those shown in Fig. 1 carry the same reference numerals and the duplicate description is to be omitted.

During processing of the specimen by the generation of plasma, controlling the capacitance, for example, of the variable capacitor 19 can control the voltage applied to the Faraday shield 18, with the result that deposition of radicals or reactive products on the wall of the dielectric body 14 can be suppressed.

It is difficult to apply the shield voltage to the inner wall surface of the dielectric body 14 opposing to the opening portions of the Faraday shield 18. Then, when the Faraday shield 18 is rotated during processing of the specimen, to alternate the opening portions and the metal portions with each other, it is possible to prevent uneven scraping of the dielectric wall 14 or prevent uneven deposition of reactive products on the wall of the dielectric body 14.

Further, in a case where the ceiling part 18b of the vacuum reactor is completely covered with the Faraday shield,

standing waves at the TM01 mode are sometimes formed in the plasma on the ceiling part, resulting in plasma density with the convex distribution. In such a case, it is preferred to dispose the opening portion 181 or a recess 182 at the center of the Faraday shield 18b.

Figs. 3(a) and 3(b) are views for explaining a further embodiment of the invention. Fig. 3(a) is a view showing an example in which the output of the second high frequency power source 9 shown in Fig. 1 is supplied by way of a power divider 20 and a phase shifter 21 to a second electrode (shield electrode) 15 and Fig. 3(b) is a view showing an example where the output of the second high frequency power source 9 shown in Fig. 2 is supplied by way of a power divider 20 and a phase shifter 21 to the coils 17. In the figures, portions identical with those shown in Figs 1 and 2 carry the same reference numerals and the duplicate description is to be omitted.

As shown in Figs. 3(a) and 3(b), the second high frequency wave source is supplied instead of the third high frequency wave 16 to the second electrode 15 or coils 17. The power divider 20 and the phase shifter 21 divisionally apply the output of the second high frequency power source to the antenna electrode 51 and the second electrode 15. In addition, the ratio and the phase difference of the voltages applied to the antenna electrode 51 and the second electrode 15, or the

antenna electrode 51 and the coils 17 can be controlled by controlling the power divider 20 and the phase shifter 21.

This can control the voltage applied to the second electrode (shield electrode) 15 or the shield electrode 18.

For example, in a case where the phase difference between the voltage of the second high frequency power source 9 and the voltage of the shield electrode is 180°, the potential on the wall of the dielectric body 14 is identical with the plasma potential when the specimen is drawing the ions, and the plasmas no more hit on the wall. On the other hand, when the potential on the specimen becomes positive, the potential on the wall of the dielectric body 14 is lowered relatively to draw ions.

That is, deposition of films on the wall of the dielectric body 14 can be suppressed by controlling the time for "deposition" and "removal" of the radicals or the reactive products on and from the wall of the dielectric body 14. When the phase difference is set to 0°, the dielectric wall 14 also draws ions when the ions are being drawn to the specimen.

In a case of using a fluorocarbon gas as a processing gas, fluorocarbon radicals formed by dissociation are deposited on the specimen or the wall. Further, radicals are also formed from the fluorocarbon films upon incidence of ions. When the specimen 4 and the dielectric wall 14 deflect at the same phase, the amount of the fluorocarbon in the plasma is

increased more than that in the case of a phase difference of 180° (a loss is decreased). Accordingly, it is expected that the amount of the etchant will increase to improve the etching efficiency. While the description has been made of the case of the phase differences of 0° and 180°, the voltage and the phase difference applied to the specimen 4 and the dielectric wall 14 are preferably changed in accordance with the kind of the gas to be used and the amount of radicals or reactive products to be formed.

Fig. 4 is a view explaining a further embodiment of the invention. In a case of using a high frequency power source at UHF or VHF as the first high frequency power source 8, it may sometimes form a distinctly convex plasma distribution. This is because standing waves (TM01 mode) are formed in the sheath on the upper surface of the specimen 4.

Then, a disk-shaped cavity 22 is provided in the surface of the antenna electrode 51. A dielectric body 23 may be filled in the cavity 22 for suppressing electric discharge. The diameter of the cavity 22 is set to about the distance between the nodes of the standing waves at the first high frequency power source and the depth d is set such that the effective distance $d^* = d/\sqrt{\varepsilon\gamma}$ ($\varepsilon\gamma$: specific dielectric constant of the dielectric body) is approximately the thickness of the specimen to be used. This can generate uniform plasma and can uniformly apply the high frequency

potential to the specimen.

Fig. 5 is a view for explaining a further embodiment of the invention in which Fig. 5(a) is a view showing a plasma processing apparatus and Fig. 5(b) is a view showing the bonding energy for the wall material and the radicals.

In this embodiment, the surface of the dielectric wall 14 is coated with the flame-sprayed film of ZrO_2 or ZrO_2-Y_2O_3. Further, the surface of the ground material 24 is also coated with the flame sprayed film of ZrO_2 or ZrO_2-Y_2O_3. Fig. 5(b) shows calculated values for the bonding energy of the wall material and the radicals determined by a molecular orbital method. A positive bonding energy shows that the radicals are adsorbed to the wall, while a negative bonding energy shows that they are not adsorbed, and the magnitude of the energy corresponds to the magnitude of the adsorption force. SiO- shows that the wall material is made of quartz and the adsorption side is O, while AlO shows alumina, and ZrO- shows zirconia.

Assuming a case of using aluminum-alumite coating for the ground material, the following can be considered. Al, Al_2O_3 and F are reacted to form AlFx, which is released into the plasma. AlF_3, AlF_2 and AlF are adsorbed to the quartz of the wall with the bonding energy at 1.52 eV, 5.58 eV and 3.49 eV, respectively. Further, when AlF is adsorbed further on AlF deposited on SiO, it is adsorbed weakly at the bonding

energy of 0.50 eV. On the other hand, SiF_4 as a typical reactive product formed by etching cannot be deposited on AlF. Weak bonding of AlF on AlF causes a problem, in which Al is detached from quartz to form obstacles as the processing for the specimen proceeds.

Further, CF_2 as the etchant is bonded to AlO at 3.78 eV in which bonding energy between Al and OCF_2 is as remarkably small as 0.71 eV. This shows that incidence of ions extracts O from AlO (alumina: Al_2O_3) to cause etching.

On the other hand, in a case of ZrO_2, CF_2 is adsorbed (at 3.78 eV), in which the bonding energy between Zr-OCF_2 is as high as 1.78 eV, showing that they are not etched easily by incidence of ions compared with the case of aluminum or alumite. Also in the case of Y_2O_3, since O is not detached easily by deposition of CFx, the surface of the compound may be stabilized also by adding Y_2O_3 to ZrO_2. While an example of coating the dielectric wall 14 with ZrO_2 is shown, only the ground material 24 may be coated with ZrO_2 or ZrO_2-Y_2O_3 while leaving the dielectric of quartz as it is depending on the case.

As has been described above, according to each of the embodiments of the invention, in the plasma processing apparatus of generating plasma by using high frequency waves of VHF or UHF band, deposition of the radicals or the reaction products and sputtering by plasma can be prevented to decrease

the cost of consumption components such as wall materials (COC) by controlling the potential or the phase thereof on the surface of the dielectric as the wall. Further, no electrode is provided on the surface of the dielectric opposing to the antenna electrode. Accordingly, the potential on the wall surface can be optimized by controlling the potential of the shield electrode formed on the outer circumferential wall of the vacuum reactor. This can decrease the formation of obstacles from the wall, extending the period of maintenance.

As has been described above, the present invention can provide a plasma processing apparatus capable of extending a period of maintenance and continuing stable processing.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.